Technical Report RSC-9

RADAR SCATTEROMETER DATA ANALYSIS: SEA STATE

NASA/MSC MISSION 20 and MISSION 34

by

Richard W. Newton

May, 1970

supported by

National Aeronautics and Space Administration

NASA Grant ~~NsG-239-~~62

NGL-44-001-001

TEXAS A&M UNIVERSITY
REMOTE SENSING CENTER
COLLEGE STATION, TEXAS

Technical Report RSC-09

RADAR SCATTEROMETER DATA ANALYSIS: SEA STATE

NASA/MSC Mission 20 and Mission 34

by

Richard W. Newton

I. INTRODUCTION

Mission 20 and Mission 34, which are the subject of this report, were flown as part of a National Aeronautics and Space Administration program involving the NASA 926 Convair 240A aircraft. Included among the sensors aboard the aircraft was Ryan Redop radar scatterometer. Using the data recorded with this 2.25 cm wavelength radar scatterometer, an attempt was made to discover any characteristics which would distinguish the two sets of data from one another. Previous work with radar scatterometer data has supported the application of the sensor to determining general sea surface characteristics for low sea states. The missions were flown over different areas of the Atlantic Ocean involving two different types of sea; therefore, by extracting characteristic information from each set of data, the surface conditions could be inferred.

The analysis discussed in this report was basically approached from an empirical sense and was only concerned with the information contained in the scatterometer data. Only part of the data recorded during Mission 20 and Mission 34 was available for analysis. It was acknowledged that errors could be inherent in these data; however, the analyses techniques did exhibit the fact that information relating to sea state was contained in the data. Unfortunately, due to the lack of sufficient ground truth, further conclusions could not be drawn.

II. THE SCATTEROMETER

The Ryan Redop radar scatterometer transmits a vertically polarized continuous wave signal with a 2.25 cm wavelength. The radar return is recorded from an illuminated region 3° wide and ±60° along the flight line. Fore data is that return collected within the +60° and aft data that collected in the -60° part of the beam (Figure 1). In order to obtain a scattering coefficient at each of several angles within the beam, the return is processed through doppler filters. The return is then time shifted in such a way that regardless of the angle at which the data are recorded, the return is from a particular "cell" on the surface of the ocean. In this manner a plot of scattering coefficient vs incidence angle can be plotted for each cell, therefore constituting a "signature" for each cell. At a 1000 feet altitude each cell is approximately 30 meters on a side. (Rouse 1969)

III. COMMENTS ON THE DATA

Mission 20, which was in support of the NAVOCEANO and the NASA-OSSA Experiments Program, was flown March 7, 1966 over the area of the ocean which encompasses the Argus Island tower and Plantagenet and Challenger Banks in the Bermuda Islands. Data available from this mission were taken during:

Flight	Line	Run	Direction of Data
2	1	3	Aft
2	2	2	Fore
2	4	1	Fore
2	4	2	Fore

Mission 34, which was also conducted in support of the NASA-OSSA Earth Resources Survey Program, was flown December 10, 1966 over an area of the North Atlantic which is directly off the coast of the United States at the boundary of Virginia and North Carolina. This area is between longitudes 73°30'W and 74°W and latitudes 36°N and 36°30'N. Data available from this mission were taken during:

Flight	Line	Run	Direction of Data
2	1	3	Fore & Aft
2	1	4	Fore & Aft

The only ground truth available to accompany the data was a general description of the sea at the time of the flights. The wind direction was unknown. During Mission 20 there were 5-foot swells, and at the time Mission 34 was flown the wind was #2 on the Beaufort scale which indicates very low sea state.

Small errors were introduced into the data due to the method by which it was necessary to put it into workable form. The data were obtained in the form of scattering coefficient versus incidence angle plots for each cell of radar return. It was then necessary to tabulate these data by manually measuring the scattering coefficient for each angle of incidence from these graphs. The data were then placed on IBM cards so that it could be used in conjunction with computer programs. However, the data reduction method introduced a possible .25db error in each scattering coefficient reading. It was assumed that for any particular angle of interest the errors in all the scattering coefficients of a run were random as to which direction this .25db error was introduced (i.e. + .25db or -.25db), therefore the average scattering coefficient of each angle was not altered.

IV. ANALYSIS TECHNIQUES

The basic objective of the analysis discussed in this report was to determine if there is a difference in the radar return over low sea state, as in Mission 34, from that of Mission 20, which was assumed to be recorded over higher sea state. Two techniques were used in order to extract information from the data. One technique was concerned with the average sigma (scattering coefficient) versus theta (incidence angle) plots for each run of data. These average plots were generated for each run of data using the average sigma at each particular angle. Data were recorded at nine angles both fore and aft during each mission, however, only the readings of the first six angles from the nadir were used for analysis. During Mission 20, data were recorded at 4.5°, 9°, 13.5°, 23°, 32.5°, and 37°. The last three angles of the nine were disregarded because the backscatter for angles greater that 40° or 45° was very small, i.e. near the noise level of the equipment used in taking the data. For this reason no information could be obtained from the data collected at these angles. After calculating the average scattering coefficient for each angle of each run, the equation

$$\sigma_0 = -15\log(\cos^4\theta + Q\sin^2\theta)$$

was fitted to these points by using a least squares curve fitting routine (Eppes 1969). This equation comes from Kirchhoff's method of predicting an average far-zone backscatter power for a plane wave incident upon a random surface with Gaussian height distribution (Hagfors 1964). From this relationship, a plot of the scattering coefficient as a function of incidence angle was generated with the "roughness factor", Q, as an independent parameter. As the slope of the curve changes, Q changes, thereby indicating some type of information about the data. Plots such as this were made for each run of both missions (Figure 2 & 3). However, since the above equation forces any curve generated using that equation to go through the origin, it was found that the equation as is could not be fitted to the experimental points. It was found, however, that shifting the origin from zero the first incident angle while fitting the curve to the experimental points, and then plotting this curve with respect to the original origin would result in a curve which fits the points reasonably well. The curve was generated assuming the origin at 5° for the data from Mission 20 and at 2.5° for Mission 34. The curves were then plotted using the original origin. Shifting the origin in this manner destroys the theoretical aspects of the equation, but the curves, and thus Q values, generated from the equation are still of possible use in an empirical sense. It is useful if the Q values generated from data taken over different sea states vary with the sea state.

The Q values for different runs are tabulated in Table I. From this table it is evident that the values of Q for Mission 20 are much higher than those of Mission 34. The lowest Q of Mission 20 is 457.70 (Line 4 Run 1 Fore data) and the highest for Mission 34 is 237.94 (Line 1 Run 3 Aft data). There is a definite separation between missions, however, these results are not in agreement with theoretical expectations.

It was reported that Mission 20 was flown over 5-foot swells while Mission 34 was flown during low winds, Beaufort #2, therefore very low sea state. The sea state during Mission 34 was supposedly the lower of the two, therefore, the scattering coefficient at higher incidence angles should fall off rapidly while for Mission 20 it should not fall off so rapidly. Q is an indication of the slope of the average sigma versus theta curve, thus, Q should be higher for the runs of Mission 34. This descrepancy could be due to the fact that while Mission 20 had 5-foot swells it is possible that the sea state on these swells were at a minimum, less than the sea state encountered during Mission 34. This is a possibility since swells are a result of past and/or remote weather conditions while "sea" rides on the swell and is a result of present wind fields in the general area of interest. Assuming this possibility, the values of Q could indicate that the major part of the radar backscatter resulted from the smaller sea state rather than the larger more uniform swells. However, due to the possibiltity of erroneous data or misreported ground truth, no conclusions can be drawn.

After inspecting the various values of Q for each mission (Table I), it appears that they are dependent upon the direction of the flight relative to the wind direction. The direction of the wind is unknown, therefore no statements can be made from the data in this respect.

Another analysis technique, the slope-intercept method (Lundien 1966), was concerned with the sigma versus theta plots for each cell of each run in order to obtain a cluster plot which would hopefully define the sea state. This technique involved fitting a straight line to the first four points of the sigma versus theta plots of each cell of radar return. In this manner two types of information can be extracted from each sigma plot and the information plotted against each other. The information is the slope and 0° intercept of the straight lines (Figure 4) (Eppes & McFarland 1969). With this data for each cell of a run, the slopes and 0° intercepts of the complete run can be plotted with the slope as the ordinate and the 0° intercept as the abscissa, forming a cluster (Figures 5 & 6). Due to the large volume of data from Mission 20, only every tenth cell was considered using this technique, thereby giving a representative sample without an excess of computer storage. An average slope and 0° intercept was also calculated for each run of data. These averages were plotted to better indicate the separation between the cluster plots of various runs (Figure 7).

After examining the clusters from both missions it is evident that there is a definite separation. The clusters of Mission 34 are higher (smaller slope) than Mission 20, however, they are generally vertically alligned (0° intercepts are approximately the same). This indicates that the 0° intercept contains little information about the sea state, since Mission 20 and Mission 34 were flown over different sea states. Clusters from both missions indicate that the slope and 0° intercept have a definite dependence upon each other due to the shape of the clusters. This is obvious from the method by which they are calculated. For this reason the slope and 0° intercept are not independent enough to contain two separate types of information.

After examining the cluster plots for each run of both missions it becomes apparent that the plots of Mission 20 are not as tightly grouped as those of Mission 34. This seems to indicate that the data of Mission 20 is possibly less consistant, and thus less accurate for the purpose of this discussion, than that of Mission 34. To better determine the accuracy of the data the mean variance and mean deviation for each angle of every run was calculated using

$$\text{Mean Variance} = \frac{\sum_{1}^{DATAP} (\text{Diff } (I)^2)}{DATAP}$$

$$\text{Mean Deviation} = \frac{\sum_{1}^{DATAP} (|\text{Diff } (I)|)}{DATAP}$$

where: Diff (I) - difference of Sigma (I) from the mean Sigma for a particular angle

DATAP - number of sigmas for the angle under consideration

The results of these calculations are tabulated in Table I. These results show that the most consistant data set should be from Mission 34 Flight 2 Line 1 Run 3 Fore data, since this run has the lowest values of variance and deviation.

This coincides with the cluster plot. This particular run gave the most compact cluster. On the other hand, Mission 34 Flight 2 Line 1 Run 3 Aft data should be the lest consistant set of data from Mission 34 because it has the highest variance and deviation. The cluster supports this, since it is the least compact of Mission 34. Overall it appears that Mission 34 contains the most consistant data of the two missions, since all of its clusters are more compact than those of Mission 20.

V. CONCLUSIONS

Due to the fact that very little ground truth accompanied Mission 20 or Mission 34, the ability to draw conclusions from the data is greatly stifled. It would appear from the cluster plots that the higher the cluster, and thus the smaller the slope, the lower the sea state. However, for this to agree with expected results the same assumption as in the discussion of section IV. would have to be made. From these analyses it is evident that the data collected over different sea states does have different characteristics and thus the possibility of discriminating sea states.

REFERENCES

Eppes, T. A., "Discussion of the Least Squares Technique and the Developement of a Curve Fitting Subroutine," Technical Report RSC-04, Remote Sensing Center, Texas A & M University, September 1969.

Eppes, T. A. and McFarland, J. C. III, "Documentation of Two Data Analysis Subroutines," Technical Memorandum RSC-03, Remote Sensing Center, Texas A & M University, December 1969.

Hagfors, T., "Backscattering From An Undulating Surface With Applications To Radar Return From the Moon," J. Geophysical Research, vol 69, no 18, pp 3779-3784, 1964.

Lundien, J. R., "Terrain Analysis by Electromagnetic Means," United States Army Engineer Waterways Experiment Station Technical Report No. 3-693, September 1966.

Rouse, J. W., "Artic Ice Type Identification by Radar," Proceedings of IEEE, vol 57, pp 605-611, April 1969.

TABLE 1

MIS.	FLT.	LINE	RUN	SITE	DIREC	MEAN VAR.	MEAN DEV.	Q	AVG. SLOPE	AVG. 0° INTERCEPT	MAG. HEADING
20	2	4	1	86	Fore	2.27 3.21 5.21 3.74 1.08 1.64	1.15 1.41 1.77 1.48 0.81 1.01	457.7	-1.46	13.99	330°
20	2	2	2	86	Fore	2.78 4.01 5.10 3.71 1.73 2.97	1.34 1.57 1.78 1.43 0.96 1.29	733.9	-1.64	13.99	055°
20	2	1	3	86	Aft	2.29 4.26 7.40 4.91 3.30 3.56	1.23 1.64 2.17 1.76 1.45 1.15	607.1	-1.58	14.12	194°
20	2	4	2	86	Fore	3.23 5.65 13.0 18.2 12.7 10.4	1.42 1.88 2.82 2.77 2.82 2.59	916.3	-1.65	13.41	152°
34	2	1	3	138	Fore	0.82 0.45 0.87 0.39 0.58 0.40	0.73 0.48 0.55 0.51 0.62 0.51	144.4	-0.88	10.73	065°
34	2	1	3	138	Aft	20.3 23.0 3.53 2.27 1.57 0.55	3.72 3.51 1.39 1.36 1.07 0.53	237.9	-1.08	14.16	065°

MIS.	FLT.	LINE	RUN	SITE	DIREC	MEAN VAR.	MEAN DEV.	Q	AVG. SLOPE	AVG. 0° INTERCEPT	MAG. HEADING
34	2	1	4	138	Fore	0.33 0.43 0.43 1.40 0.38 13.5	0.45 0.52 0.48 0.81 0.51 1.69	174.8	-1.03	10.62	070°
34	2	1	4	138	Aft	8.23 3.25 1.24 0.73 2.73 0.22	1.62 0.72 0.76 0.69 1.06 0.34	168.8	-1.02	12.67	070°

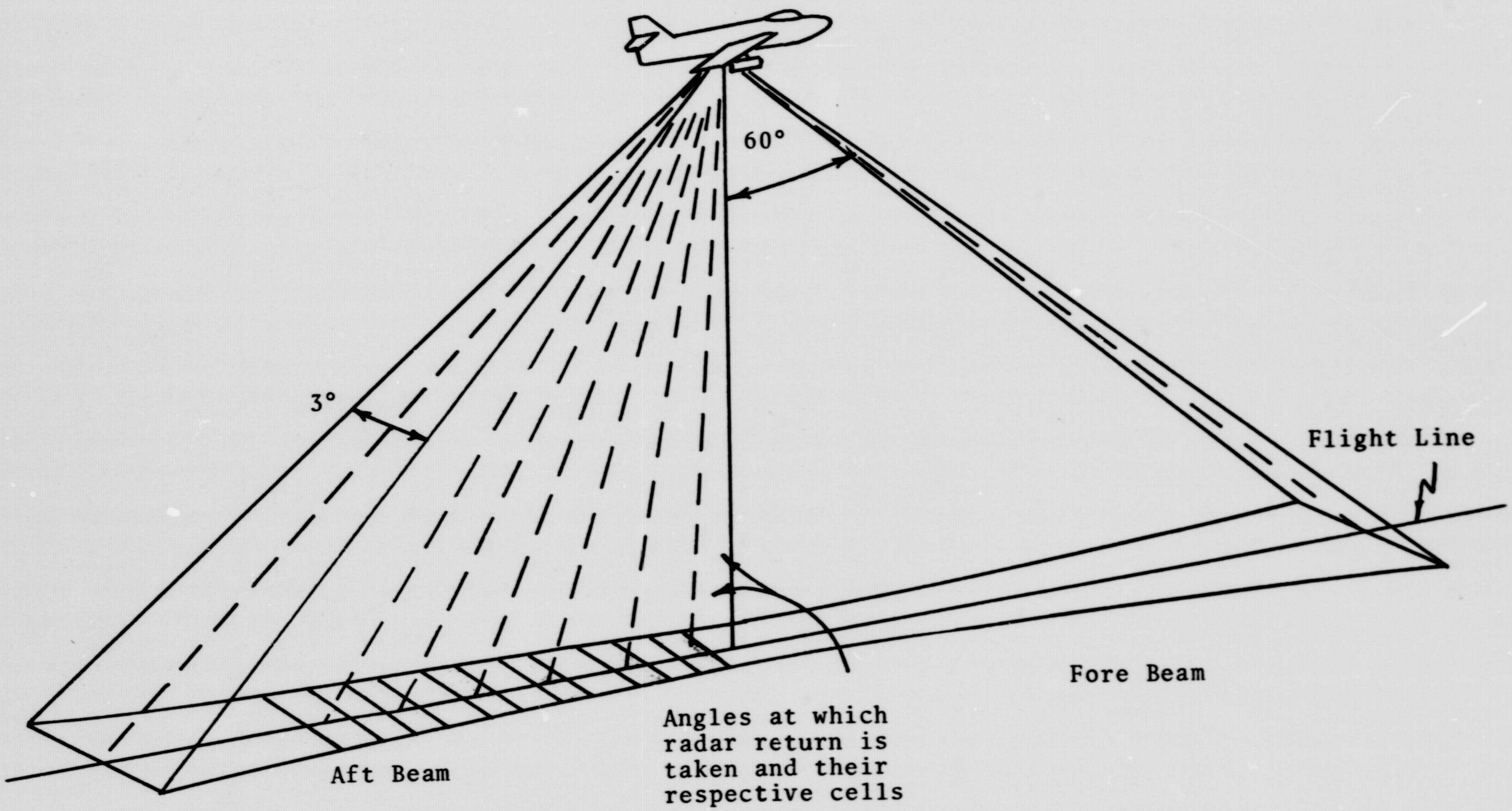
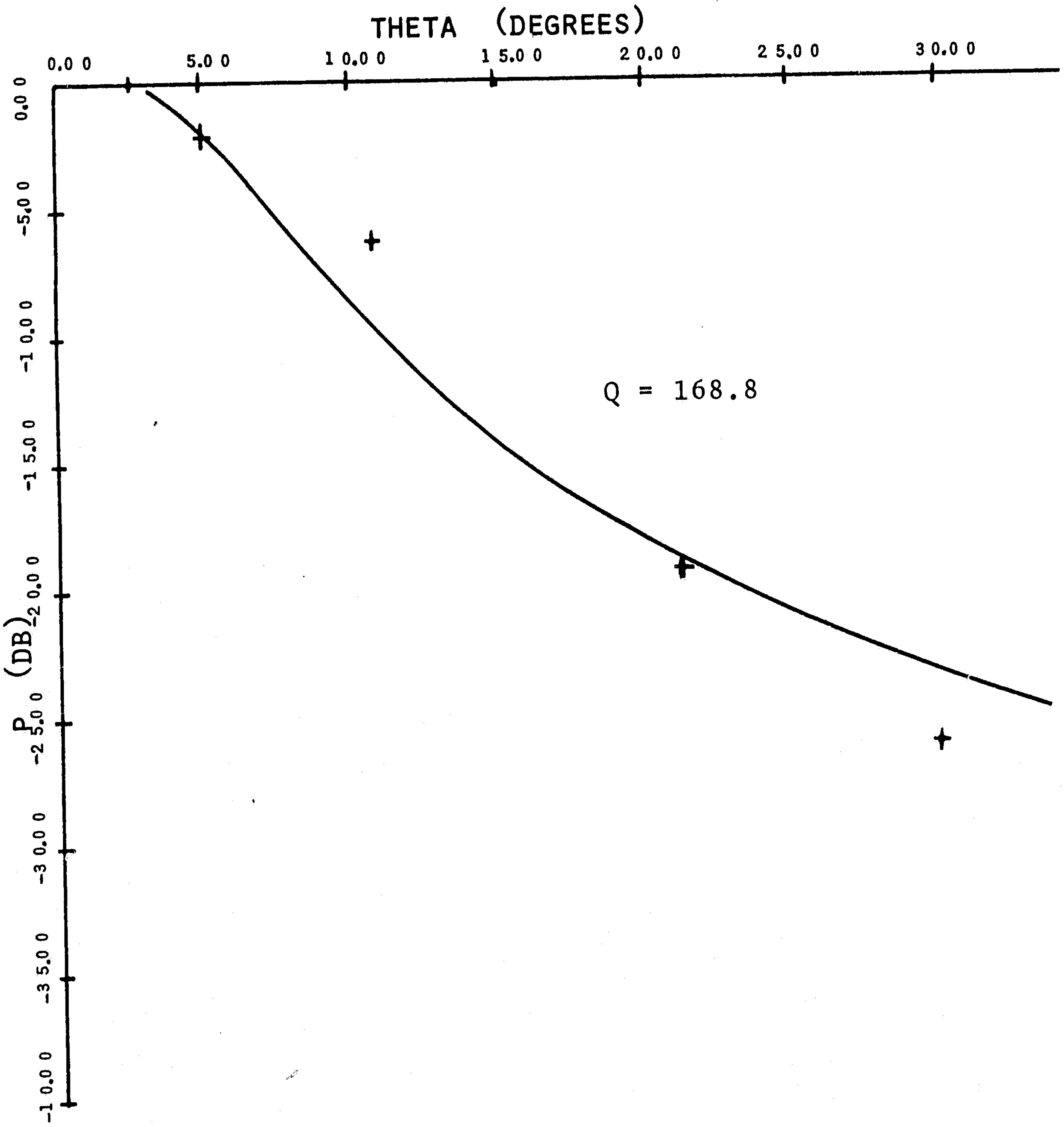


FIGURE 1 GEOMETRY OF A RADAR SCATTEROMETER

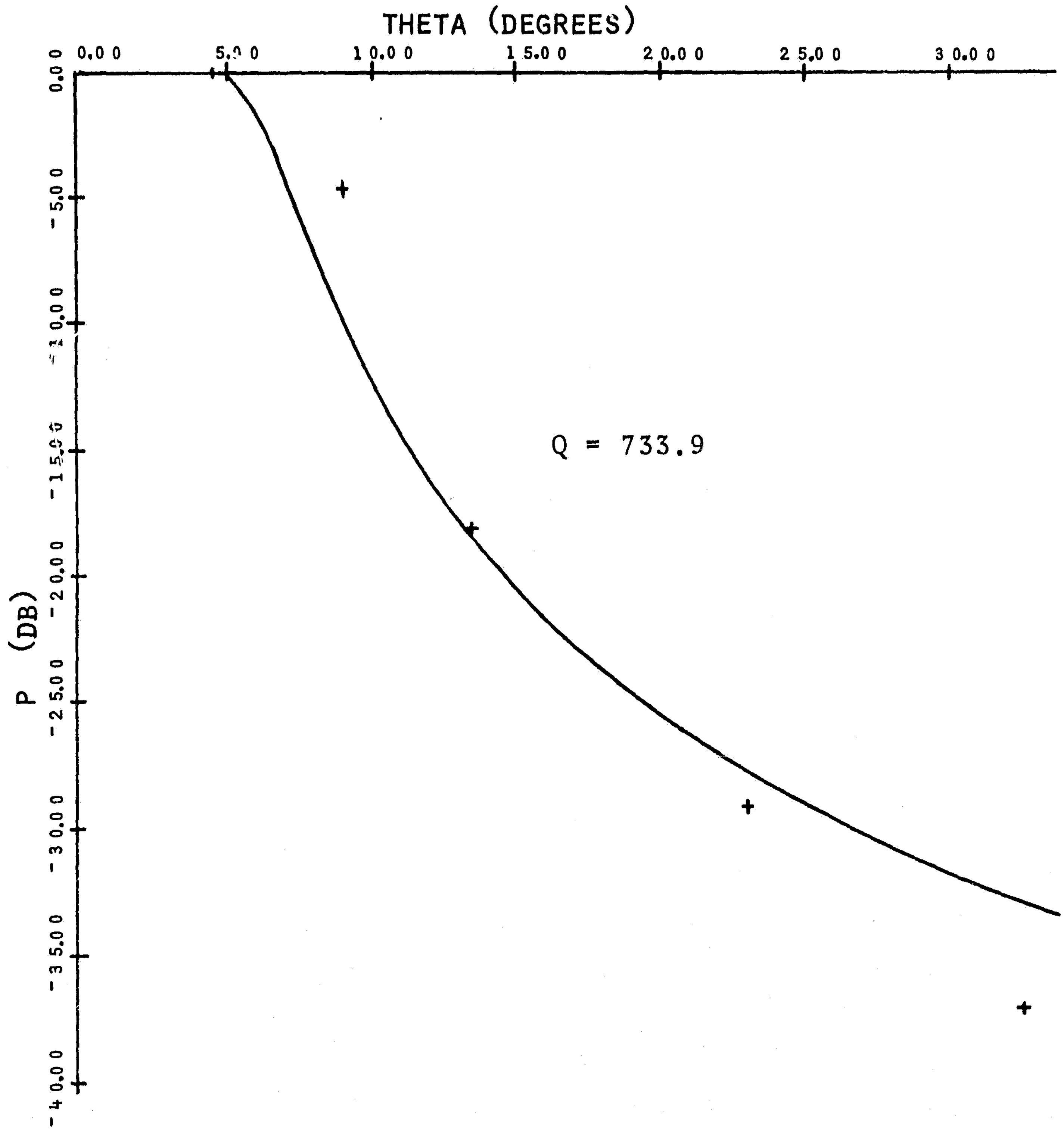
NORMALIZED SCATTERING COEFFICIENT VERSUS INCIDENCE ANGLE



MISSION 34 FLIGHT 2 LINE 1 RUN 4 AFT DATA

FIGURE 2

NORMALIZED SCATTERING COEFFICIENT VERSUS INCIDENCE ANGLE



MISSION 20   FLIGHT 2   LINE 2   RUN 2   FORE DATA

FIGURE 3

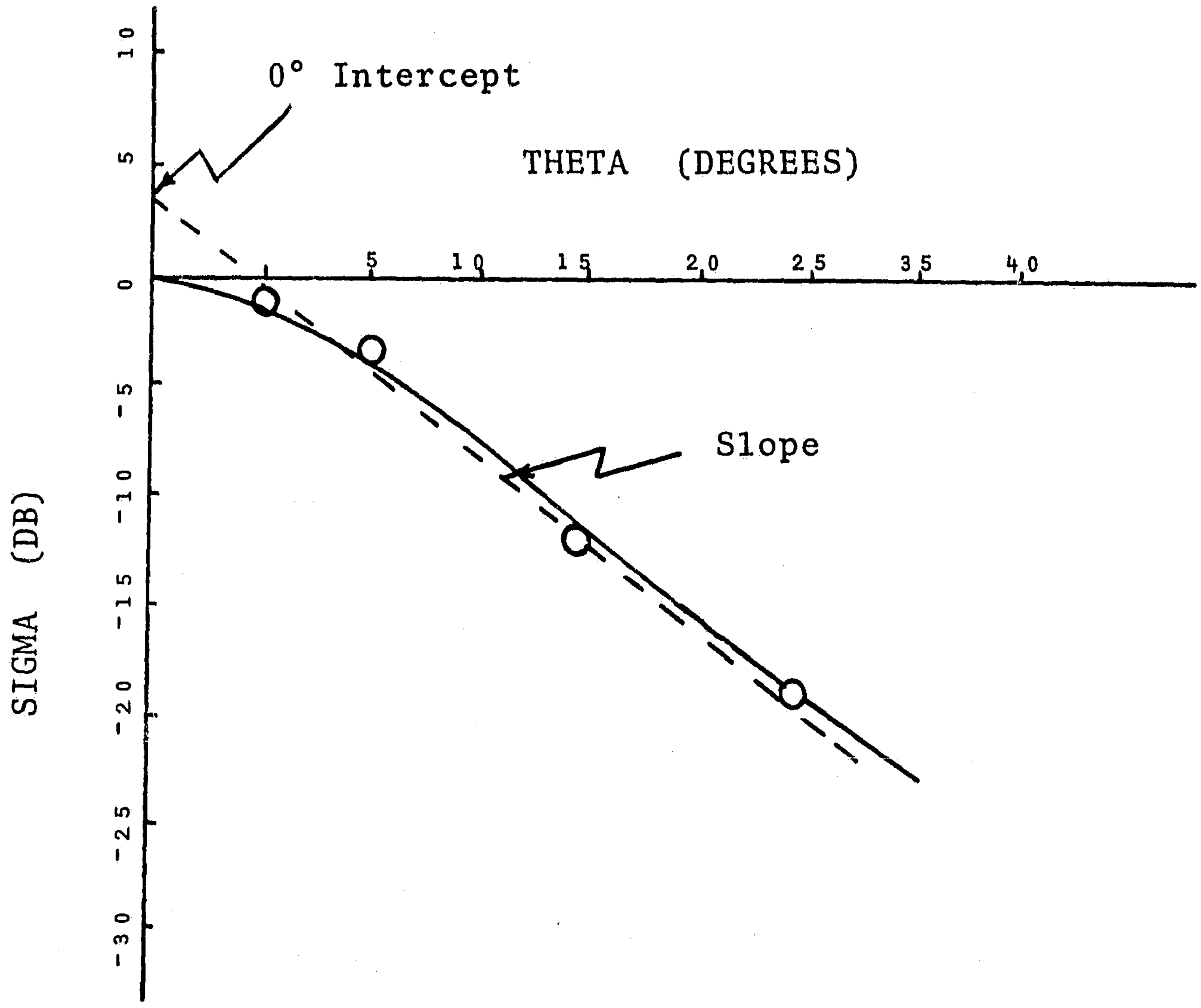
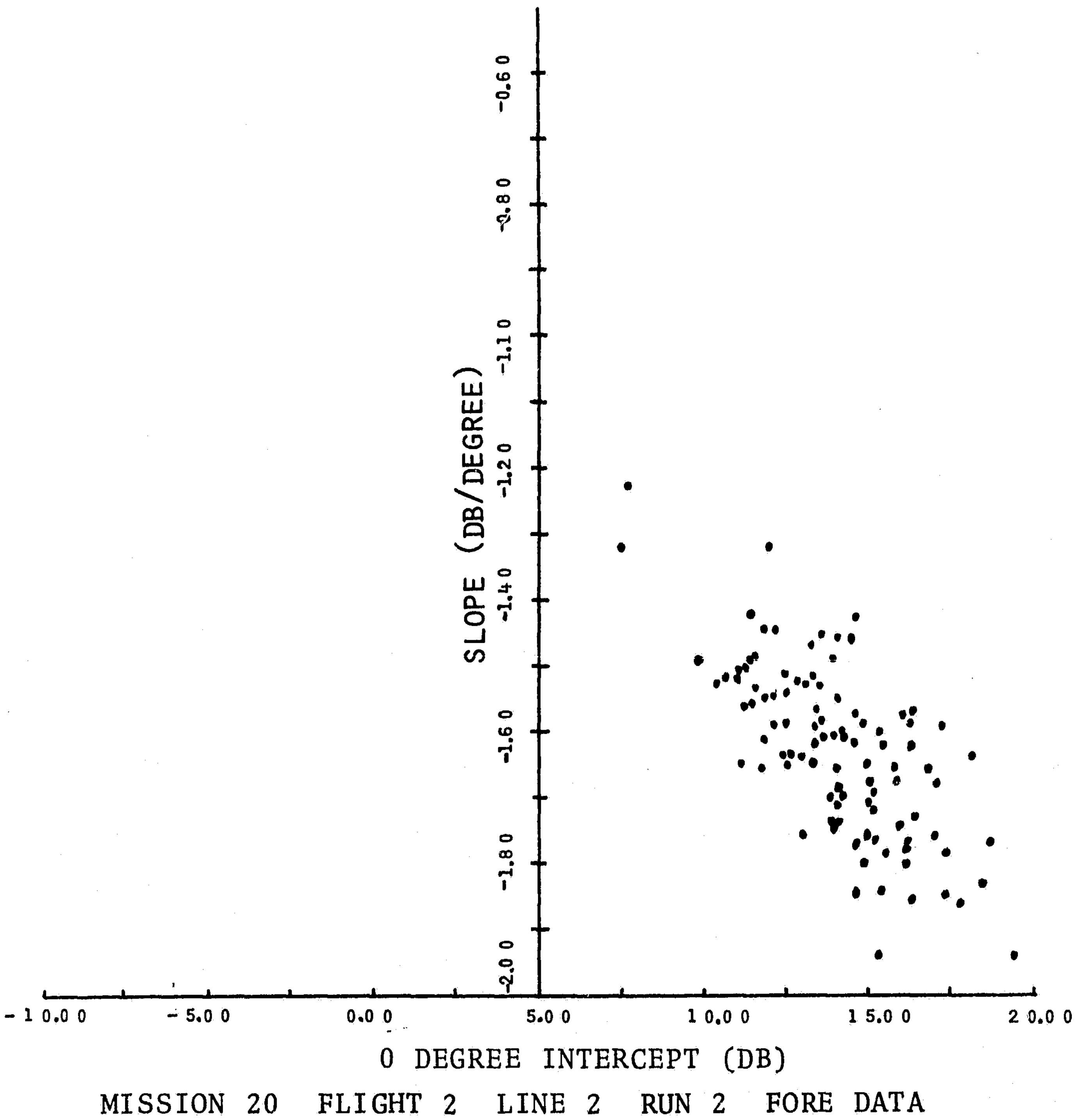


FIGURE 4 METHOD OF OBTAINING POINTS FOR CLUSTER PLOTS

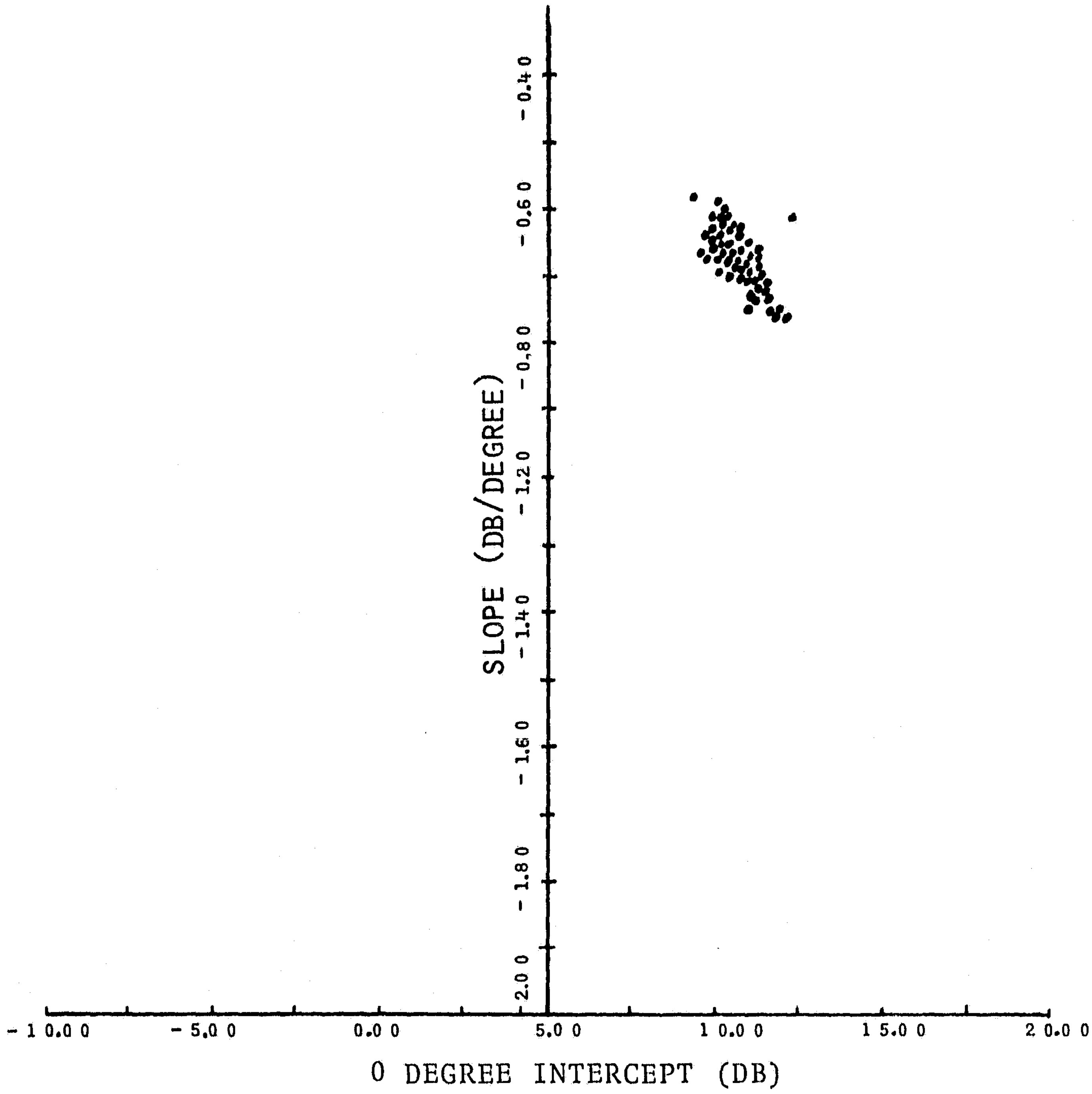
SLOPE INTERCEPT CATEGORIZATION



MISSION 20 FLIGHT 2 LINE 2 RUN 2 FORE DATA

FIGURE 5

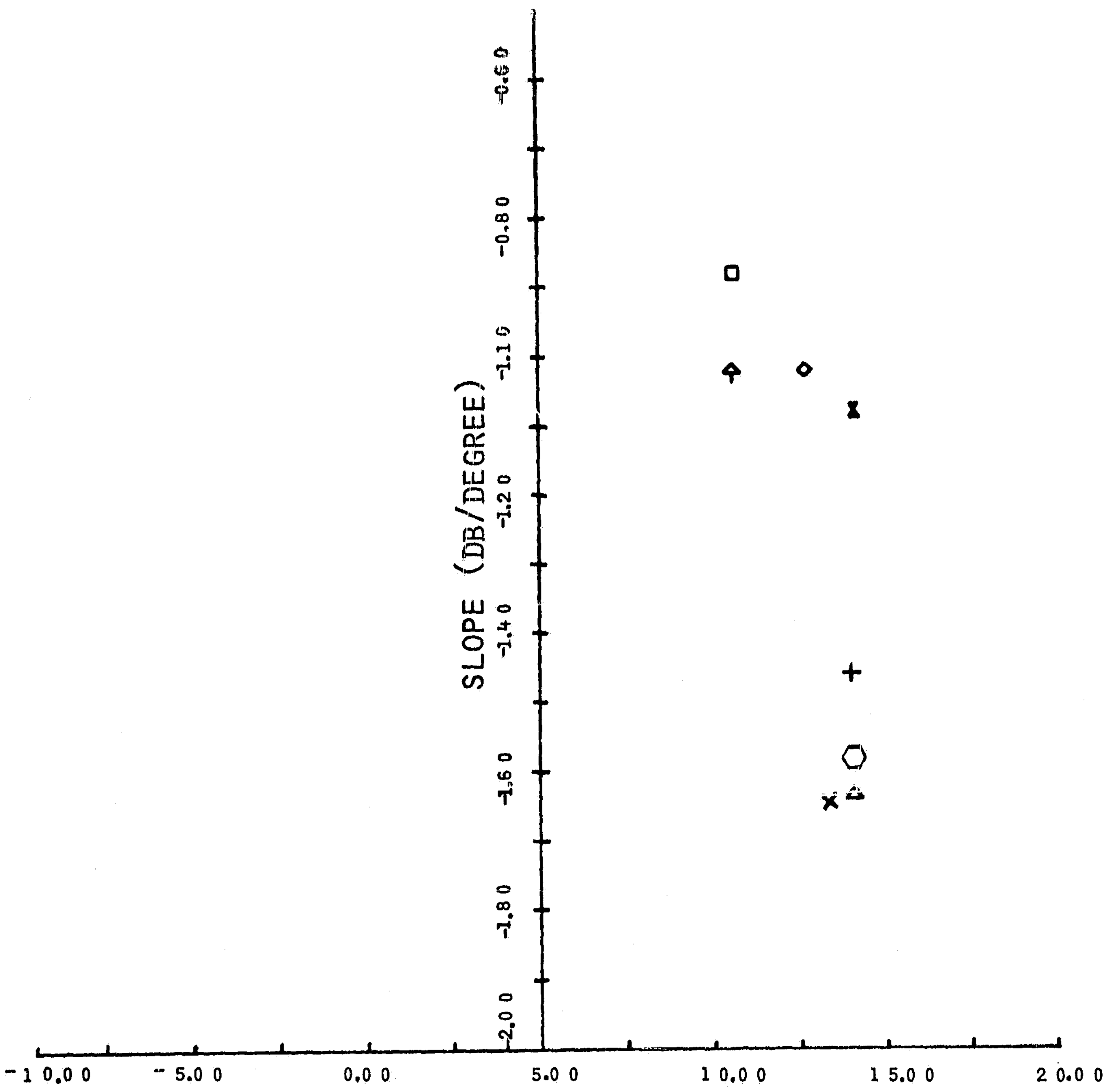
SLOPE INTERCEPT CATEGORIZATION



MISSION 34 FLIGHT 2 LINE 1 RUN 3 FORE DATA

FIGURE 6

AVERAGE SLOPE INTERCEPT POINTS FOR EACH RUN



SYMBOL	MISSION	FLIGHT	LINE	RUN	DATA DIRECTION
□	34	2	1	3	Fore
⧖	34	2	1	3	Aft
⇧	34	2	1	4	Fore
◊	34	2	1	4	Aft
⬡	20	2	1	3	Aft
×	20	2	4	2	Fore
+	20	2	4	1	Fore
△	20	2	2	2	Fore

FIGURE 7